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A Review on Recent Development In Finite Element Analysis For Laminated Composite Plates

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ABSTRACT

A review of the recent development of the finite element analysis for laminated composite plates from 1990 is presented in this paper. The literature review is devoted to the recently developed finite elements based on the various laminated plate theories for the free vibration and dynamics, buckling and large deformation analysis, and failure and damage analysis of composite laminated plates. A three-dimensional elasticity based layer-wise finite element method (FEM) is employed to study the static, free vibration and buckling responses of general laminated thick composite plates. Various mixed boundary conditions and free edge conditions are conveniently and accurately implemented.

Keywords : composite plates, free vibration, buckling and large deformation analysis.

INTRODUCTION

Composite laminates have been used increasingly in a variety of industrial areas due to their high stiffness and strength-to-weight ratios, long fatigue life, resistance to electrochemical corrosion, and other superior material properties of composites. A true understanding of their structural behaviour is required, such as the deflections, buckling loads and modal characteristics, the through thickness distributions of stresses and strains, the large deflection behaviour and, of extreme importance for obtaining strong, reliable multi-layered structures, the failure characteristics. Finite element method is especially versatile and efficient for the analysis of complex structural behaviour of the composite laminated structural.

Using finite element method, a significant amount of research has been devoted to the analysis of vibration and dynamics, buckling and failure and damage analysis and etc. A review of the finite element models developed after 1990 based on the various laminated plate theories for the finite element analysis of composite laminated plates is presented in this paper. The finite element analysis reviewed includes the following categories: free vibrations, damping, and buckling and large deformation analysis; damage and failure. Some of the future research on composite laminated plates is also summarized.

LAMINATED COMPOSITE PLATE THEORIES

The laminated plate theories are essential to provide accurate analysis of laminated composite plates, and a variety of laminated plate theories have been developed and reported in a large amount of literatures. A review of various equivalent single layer and layerwise laminated plate theories was presented by Reddy and Robbins[1]. The in-plane degrees of freedom are interpolated quadratically whereas a linear layerwise approximation is chosen for the normal displacement. A substructuring technique is used to eliminate the in-plane degrees of freedom during the assembly process thus reducing substantially the computationed costs. A layer-wise triangle for analysis of laminated composite plates and shells was presented by Salvador Botello, Eugenio On ate,Juan Miquel Canet[2] A Rivew of Mixed least-squares finite element model for the static analysis of laminated composite plates F. Moleiro, C.M. Mota Soares ,C.A. Mota Soares, J.N. Reddy[3] Analytical solutions for the static analysis of laminated composite and sandwich plates based on a higher order refined theory T. Kant , K. Swaminathan[4].

Generally, the laminated plate theories can be broadly divided into the following two categories:

- Equivalent single layer (ESL) theories, including
  Classical lamination theory (CLPT)
  The first-order shear deformation theory (FSDT)
  Higher-order shear deformation theories (HSDT)
  Layer-wise lamination theory (LLT)

- Continuum-based 3D elasticity theory
  Generalized laminate plate theory (GLPT)

FREE VIBRATION AND DAMPING ANALYSIS OF COMPOSITE LAMINATED PLATES

Computational models based on CLPT

The classical laminate plate theory (CLPT) is based on the Kirchhoff plate theory, it is the simplest theory among others, but the shear deformation effects are neglected. The first-order shear deformation theories (FSDT) provides a balance between computational efficiency and accuracy for the global structural behaviour of thin and moderately thick laminated composite plates, but no accurate prediction for the local effects can be obtained, for example, the inter laminar stress distribution between layers, delimitations, and etc.

Various higher-order shear deformation theories have been developed to overcome the limitations in the classical and first-order shear deformation theory, and the free boundary conditions of the transverse shear stresses on the upper and lower surfaces can usually be satisfied. Layer-wise lamination theory assumes a displacement representation formula in each layer. It can predict accurately the inter laminar stresses; however layer wise models are computational expensive since the number of unknown functions depends on the number of the layers of the laminates. The 3D continuum- based theory can predict the inter laminar stress of a composite laminate, but the computational cost using 3D models is a major concern.

Even as plates on elastic foundations are often encountered in many practical applications, the analysis of a general prob-

lem of thickreinf orced laminated plate resting on elastic foundation with point and line elastic supports, has not hitherto been addressed by three-dimensional layer-wise theory. In this paper, a generalized layer-wise laminated plate theory based on a three-dimensional approach for static, vibration, and buckling analysis of fiber reinforced laminated composite plates been developed. The layer-wise theory is refined to take into account the variation of the variables through the thickness [5].

Computational models based on FSDT

The first-order shear deformation theory (FSDT) has been employed widely to establish finite element models for free vibration analysis of the composite laminated plates. The effects of lamination and extension–bending coupling, shear and twist-curvature couplings on the lowest frequencies and corresponding mode shapes for free vibration of laminated anisotropic composite plates was investigated using a finite element method with quadratic interpolation functions and five engineering degrees of freedom (DOF) [6].

Linear static analysis and finite element modeling for laminated composite plates using third order shear deformation theory was presented by M. Rastgaar Aagaah, M. Mahinfalah , G. Nakhaie Jazar [7]. Analytical solutions using a higher-order refined theory for the static analysis of antisymmetric angle-ply composite and sandwich plates was presented by K. Swaminathan , D. Ragounadin [8].

In their work, the layers of the laminated plate were modelled using nine-node isoparametric degenerated flat shell element, and the stiffeners were modelled as three-node isoparametric beam elements based on Timoshenko beam theory. Bilinear in-plane displacement constraints were used to maintain the inter-layer continuity, and a special lumping technique was used in deriving the lumped mass matrices.Damping analysis of composite laminated plates has been carried out using the computational models developed based on the FSDT. The effects of transverse shear deformation on the modal loss factors as well as the natural frequencies of composite laminated plates was investigated using a finite element method based on the shear deformable plate theory [9].

Computational models based on HSDT

Considerable amount of free vibration analyses of various composite laminated plates has been studied using the finite element models developed based on different kinds of higher-order shear deformation theories.

Static analysis of functionally graded plates using third-order shear deformation theory and a meshless method was presented by A.J.M. Ferreira , R.C. Batra , C.M.C. Roque , L.F. Qian , P.A.L.S. Martins [10] .Various schemes for the generation of the mass matrix were discussed and a comparative study of these schemes was presented . Based on Reddy's higher-order theory, a finite element formulation taking into account the parabolic distribution of the transverse shear deformation through the thickness of the plate was presented for vibration analysis of laminated anisotropic plates with different lay-ups and of sandwich plates [11].

Computational models based on layer wise theories LLT

Compared with the computational models for the free vibration and damping analysis developed based on the FSDT and HSDT, relatively few models were developed based on the Layer wise theories. The computational model developed based on the layer wise theories include the 18- node, three-dimensional higher-order mixed model for free vibration analysis of multi-layered thick composite plates [12], in which the continuity of the transverse stress and the displacement fields were enforced through the thickness of laminated composite plate, the hybrid strain-based layer wise shell element for free vibration of laminated composite plate and shell structures [13] developed based on several lower-order hybrid strain-based triangular shell elements for the general nonlinear analysis of isotropic shell structures, and etc.

Buckling analysis of laminated composite plates

The buckling of laminated composite plates is an important consideration in the design process, however the critical value of load given by linear buckling analysis may not accurately represent the load-carrying capability of a plate. Although composite laminated plates generally possess less load-carrying capacity after buckling compared to their metallic counterparts, the total load during the postbuckling of a composite laminated plate is still several times that of the critical buckling load. In order to get the practical limits of the load-carrying capability of the composite laminated plates, the postbuckling behaviour has been studied to establish the sustained additional loads after buckling. Considerable efforts have been made for the numerical analysis of the buckling and postbuckling analysis over the years.

Failure analysis

Under normal operating conditions, local failures such as matrix cracks, fibre breakage, fibre matrix debonding and interlayer delamination, may be developed in the laminated composite structures, and the failure may cause permanent loss of integrity within the laminate and result in loss of stiffness and strength of the material. Prediction of the failure process, the initiation and growth of the damages, and the maximum loads that the structures can withstand before failure occurs is essential for assessing the performance of composite laminated plates and for developing reliable and safe design.

The different laminated plate theories, such as the CLT, FSDT, HSDT and layer-wise theories have been employed for failure analysis. Some progressive failure analysis of composite laminates based on the 3D layerwise plate theories have been carried out. For example, Reddy and Reddy [14] used generalized layerwise plate theory and a progressive failure model to determine first-ply and ultimate failure loads of a three-point bending specimen with geometric nonlinearity.

The failure mechanism and ultimate failure loads of the cross-ply and quasi-isotropic laminates for different stacking sequences with the same thickness subjected to axial extension was conducted [15] based on the generalized layerwise plate theory (GLPT) in order to consider the local effect near the free edges. A plate bending element based on a generalized laminate plate theory was presented by j. n. reddy· and e. j. Barber[16] analytical solution for multilayer plates using general layerwise plate theory was presented by Đorđe Vuksanović, Marina Ćetković [17].

The element accounts for transverse shear deformation and layerwise description of the inplane displacements of the laminate. The element has improved description of the inplane as well as the transverse deformation response. While the GLPT plate bending element is computationally expensive compared to the FSDT plate element (or the Mindlin plate element), it yields very accurate results for all stresses and it is less expensive compared to a three-dimensional finite element analysis of laminated composite plates.

CONCLUSIONS

The recent advances of the finite element analysis of composite laminated plates based on various lamination theories, with the focus on the free vibration and dynamics, buckling and failure and damage analysis of composite laminated plates, are reviewed in this paper. The development of buckling analysis under material nonlinearity and thermal effects are emphasised and in the failure analysis, the concentration is especially on the advances of the first-ply failure analysis.

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